United States
Environmental Protection Agency

Current and Future Emissions Standards for On-Highway and Nonroad Diesel Engines

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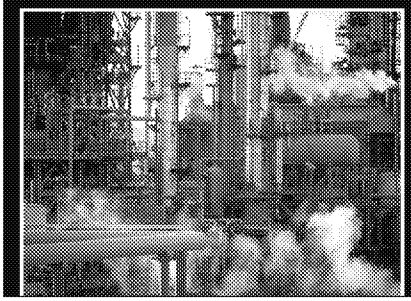


Presentation Overview

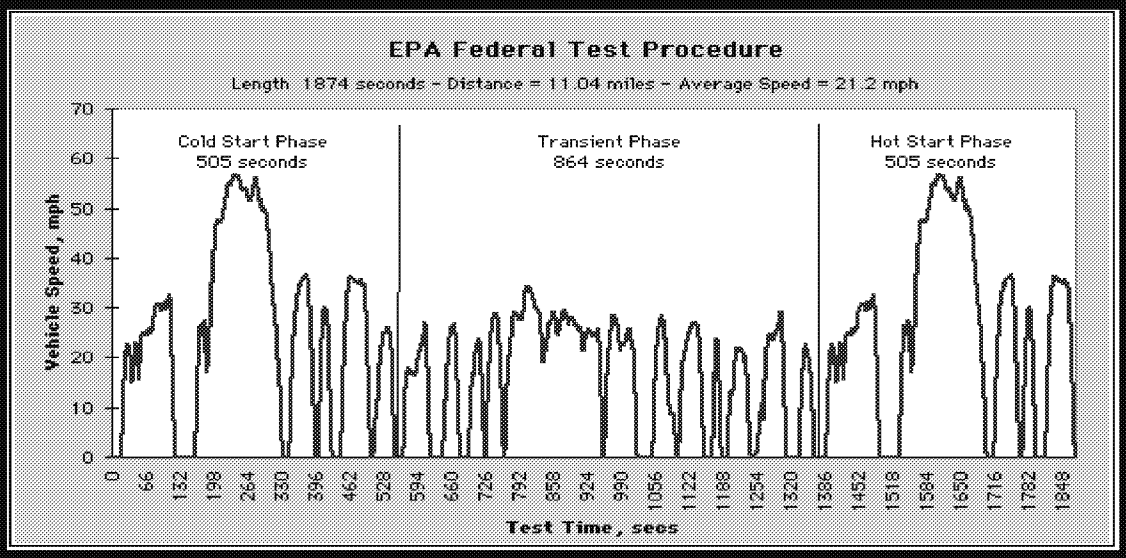
- Emissions Testing
- Need for New Standards
- Averaging Banking and Trading (AB&T)
- Diesel Fuel Control
- Emissions Control 101
- New standards
  - On-highway Heavy-duty
  - Nonroad Diesel
- Nonroad Equipment Flexibility

Emissions Testing

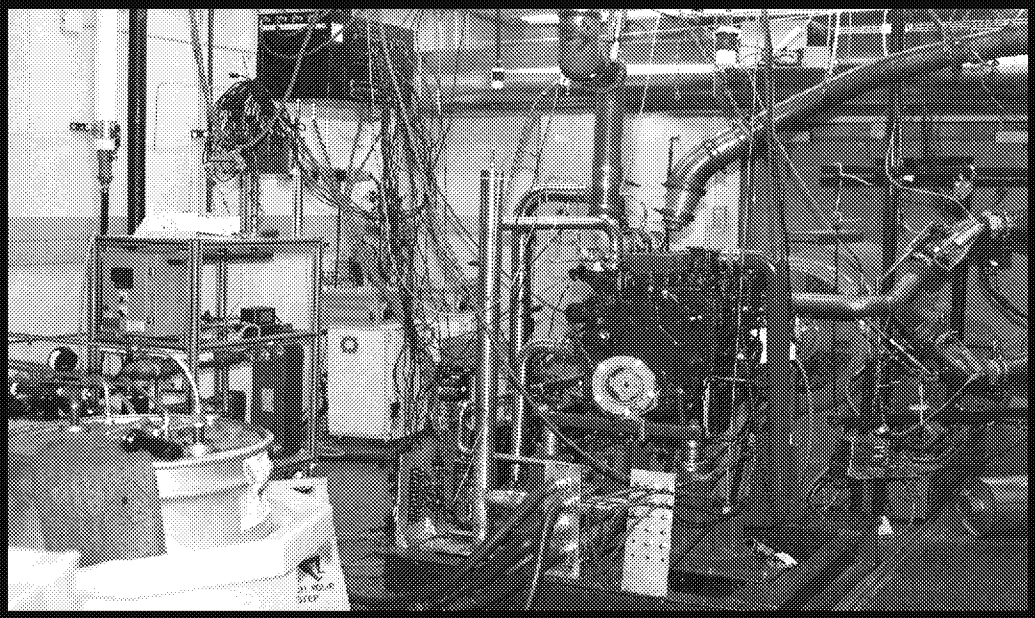
- Cars, light-duty trucks, and motorcycles are tested as complete vehicles
  - Vehicles driven on a chassis dynamometer
    - Vehicle speed versus time
  - Emissions are measured in grams per mile
  - Certification completed by Ann Arbor, MI office
- Heavy-duty trucks, nonroad equipment, and marine engines tested on an engine dynamometer
  - Too many vehicle configurations to test
  - Limited number of engine manufacturers compared to vehicle/equipment manufacturers
  - Emissions measured on a gram per work basis, g/bhp-hr or g/kW-hr
    - Engines tested at various engine speeds and loads
    - Gaseous emissions measuring continuously
    - Particulate mater captured on filters and weighed
  - Certification completed by Washington, DC office

Passenger Car Test Cell

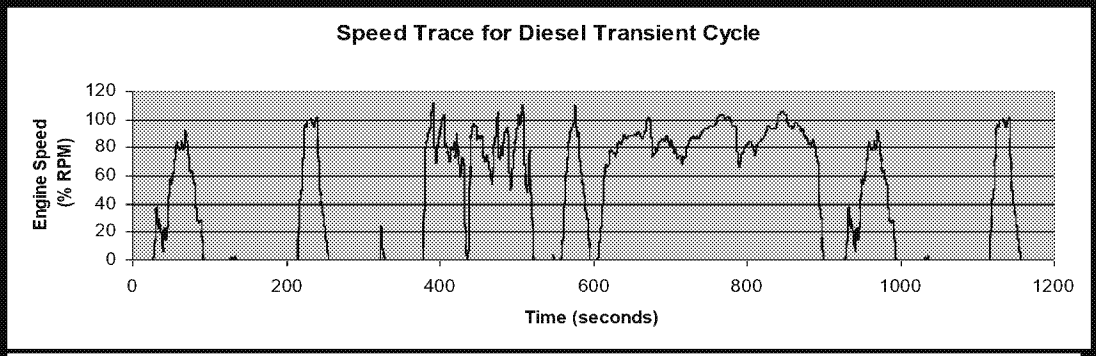
Federal Test Procedure for Light Duty Vehicles

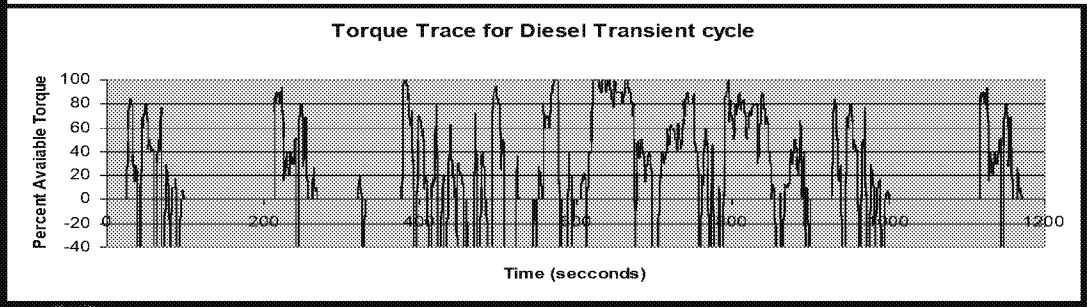


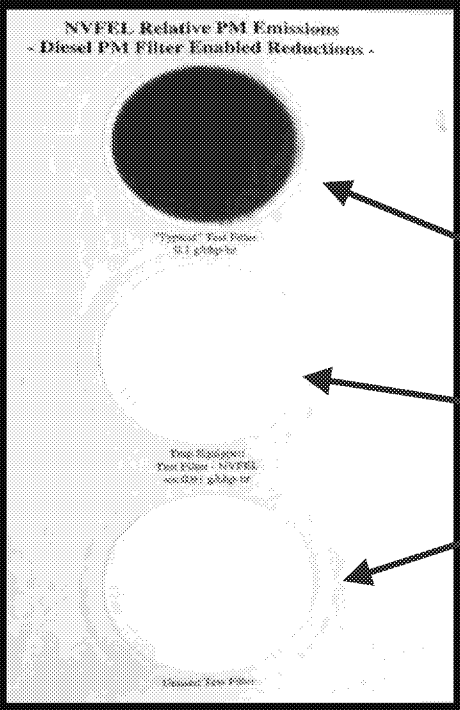
Engine Test Cell



On-highway Diesel Test Cycle







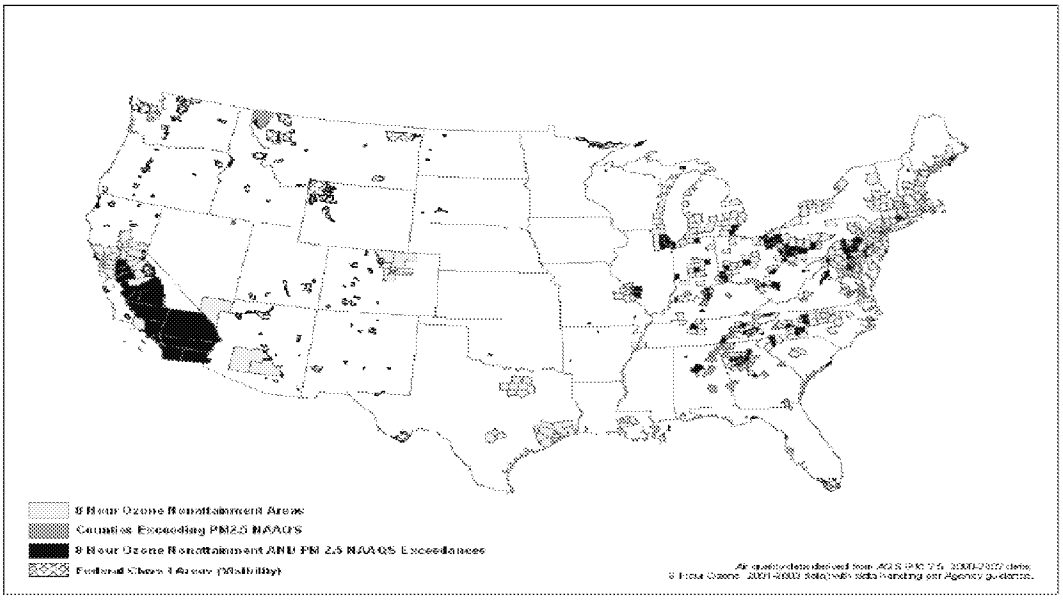
PM Emissions with Trap

- Typical test filter – current standards
- Test filter – 2007 standards
- Unused test filter

New Emission Standards

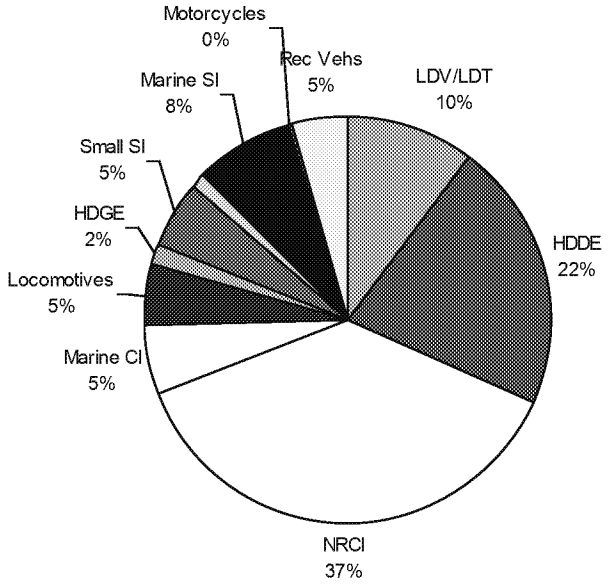
- The Tier 2 rule for passenger cars and light-duty trucks set the pattern for mobile source emissions control
  - Regulations addressed gasoline fuel and light-duty vehicles as a system
  - Reduced sulfur in gasoline enables vehicle emission control system to reduce emissions to low levels
  - 2004 model year phase-in
- 2007 on-highway diesel, Tier 4 nonroad, and proposed locomotive/marine regs are following this approach
  - Diesel engines significant sources of NOx and PM
    - NOx is an ozone precursor
  - Ultra low sulfur diesel (ULSD) < 15 ppm sulfur needed
    - Low sulfur diesel 300-500 ppm sulfur

Non-Attainment Areas in the US



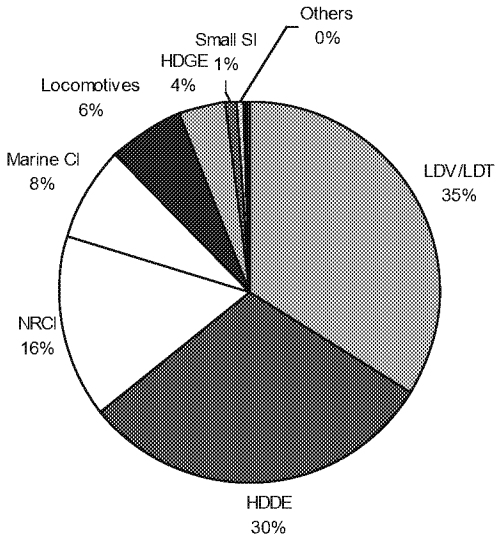
PM Mobile Source Inventory

2005



NOx Mobile Source Inventory

2005



Averaging, Banking and Trading

- Engines are certified as families
  - An engine family is a group of engine with similar design characteristics which result in similar emissions
- AB&T is a voluntary program
  - Prior to AB&T, emission standard was a bright line not to be crossed
  - AB&T allows engines certified above the emission standard to be offset by engines certified below the standard
  - Engine families in AB&T certify to Family Emission Limits (FELs)
    - An FEL, a number above or below the standard, becomes the standard for the engine family
      - An engine family with an FEL of 4.1 g/kW-hr uses credits versus a 4.0 standard
      - An engine family with an FEL of 3.9 g/kW-hr generates credits
    - Number of credits =
      - #engines x (Standard-FEL) x engine power x useful life of engine
      - Useful life is the period (miles or hours of operation, and years) engine must meet standards

Averaging, Banking, and Trading

- When a manufacturer averages, the credits are used between engine families in the same year
- Banking allows a manufacturer to accumulate credits for use in future years
- Trading allows manufacturers to sell credits to each other. This rarely happens
- Credit limitations
  - Upper FEL cap for credit users, usually the previous standard
  - Credits can only be used in the same industry
    - On-highway credits can not be used for nonroad engines

Averaging, Banking and Trading

- Credit limitations (cont.)
  - Credits are only for certification
    - PM and NOx or NMHC+NOx credits only
    - Averaging sets limit credit transfer within an industry
      - For example, light-heavy, medium-heavy and heavy-heavy for on-highway
    - Cannot be used to correct problems with in-use engines
- AB&T advantages
  - Allows engine manufacturers flexibility in meeting emissions standards
    - Set FEL to have more compliance margin
  - Allows for small volume old technology engines to stay in production after a standards change

ULSD Implementation Schedule

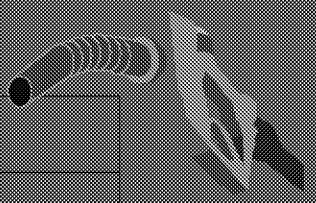
Who	Covered Fuel	2006	2007	2008	2009	2010	2011	2012	2013	2014
	Highway Diesel Fuel	80% 15 ppm / 20% 500 ppm				100% 15 ppm (including small refiner fuel)				
Large Refiner & Importer	Nonroad		500	500	500	15	15	15	15	15
Large Refiner & Importer	Loco and Marine		500	500	500	500	500	15	15	15
	NRLM with Credits (Not in NE or AK)		500	500	500	500	500	500	500	15
Small Refiner	NRLM (Not in NE, w/ approval in AK)		500	500	500	500	500	500	500	15
Transmix Processor & In-use	Nonroad (Not in NE or AK)		500	500	500	500	500	500	500	15
Transmix Processor & In-use	Loco and Marine (Not in NE or AK)		500	500	500	500	500	500	500	500

ULSD Implementation for 2007 On-highway

- Production is at 90% of MV diesel and has been since the fall of 2006.
  - At retail levels, for Q1 of 2007 data have shown 90% of pumps contain fuel that is at or below 15 ppm
  - 4-5 cents estimated increase per gallon fuel, partially off-set by maintenance savings of ~ 1 cent per gallon
    - Includes cost for lubricity improvement
  - We are still addressing the need for improved labeling so consumers are aware of the true availability of ULSD
  - Office of Enforcement and Compliance Assurance (OECA) is starting to fine retailers without proper labels
- ULSD enables aftertreatment technology

How does this rulemaking impact end users of diesel powered equipment?

Old and New Engine Maintenance Benefits From Low Sulfur Fuel



Affected Components	Effect of Lower Sulfur
Piston Rings	Reduces corrosion wear-- Extends engine life
Cylinder Liners	Reduces corrosion wear-- Extends engine life
Oil Quality	Reduces deposits & need for additives-- Reduces wear and oil change frequency
Exhaust System (tailpipe)	Reduces corrosion wear-- Less frequent part replacement
EGR	Reduces corrosion wear-- Less frequent part replacement

Emissions Control 101

- In-cylinder Control
  - Cylinder design
  - High pressure fuel
  - Injection timing retard
  - Multiple injection events
  - Internal EGR
- EGR
  - Recirculate cooled exhaust gas to lower combustion temperature and control NOx
- Diesel Oxidation Catalyst (DOC)
  - Catalyst oxidizes hydrocarbons and PM

Emissions Control 101

- Diesel Particulate Filter (DPF)
  - Soot filtered from exhaust
  - The filter is cleaned (regenerated)
    - Passively - exhaust temperatures during certain modes of normal operation are high enough to burn off soot
      - Some filters are designed to only regenerate this way
    - Actively – Once filter reaches a certain soot loading, engine computer introduces additional fuel to raise exhaust temperature and burn soot
      - Drivers made aware of need for and occurrence of regeneration
        - » In some applications, can delay regeneration until appropriate
      - Filters will eventually fill with ash and need to be removed for cleaning
        - » 150,000 miles or more for most heavy-duty vehicles
        - » May be less for vehicles which can not accommodate large enough filter

Emissions Control 101

- NOx adsorbers
  - Work like catalysts on passenger cars
  - NOx is adsorbed on to surface of catalyst
  - Once catalysts sites are full of NOx, exhaust is made fuel rich
    - Hydrocarbons in fuel react with NOx to form CO_2, N_2 and H_2O
  - High levels of sulfur in fuel will poison catalyst
    - Sulfur adsorbs on sites were NOx would normally be held
    - Even with ULSD, catalyst will occasionally need to be cleaned of sulfur.
    - Sulfur removal done under fuel rich conditions similar to NOX removal
  - Maybe too costly for all applications
    - Linehaul trucks

Emissions Control 101

- Selective Catalytic Reduction (SCR)
  - NOx is catalytically reduced by NH_3
    - $NO_X+NH_3 = N_2+H_20$
  - Liquid urea decomposed to form NH_3 in exhaust
  - SCR has been used before
    - Used on power plants
    - Used on trucks in Europe
    - Likely to be on 2008 diesel passenger cars in U.S.
    - DDC and Volvo/Mack plan to use in 2010 trucks
  - Technology requires operator to refill urea tank
    - Operator warning and incentive to refill tank
    - System must have technology ensure urea quality
    - Urea infrastructure must be in place
      - Dealerships
      - Emergency plan
      - Truck stops, gas stations, etc

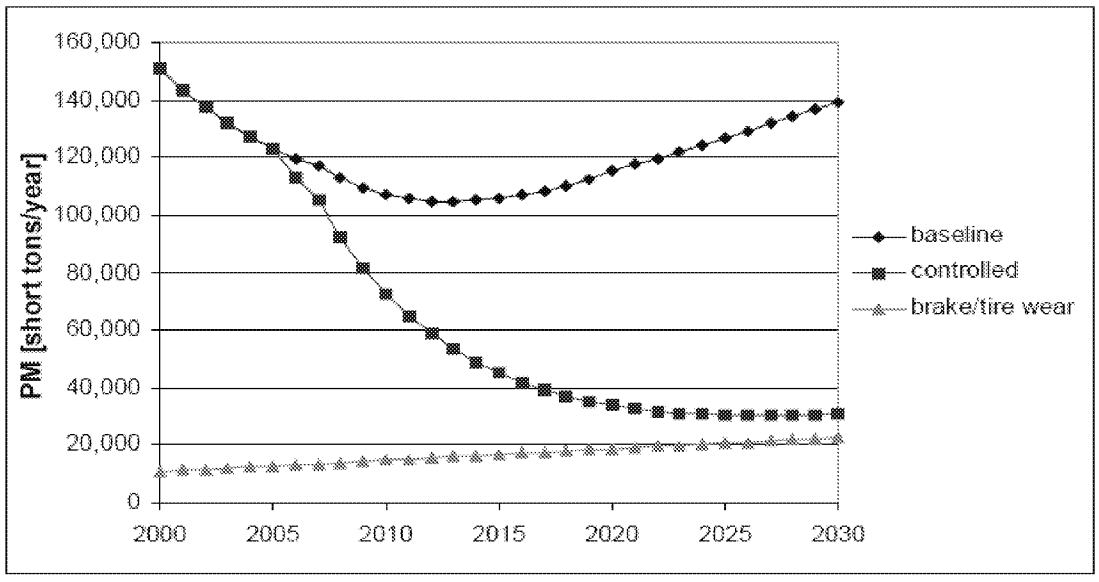
On-highway HDDE

- PM and NOx emissions will be reduced by greater than 90% by 2010
  - In 2007, vast majority of engines certified to 0.01 g/bhp-hr down from 0.10 in 2006
    - DPF required to reach this level
    - A few engines certified without DPFs through early introduction credit program
- NOx emissions standard phased in through 2010
  - 50% of 2007-2009 engines must meet 0.2 g/bhp-hr NOx
    - 100% in 2010
    - NOx aftertreatment needed for this standard
  - 50% of engines in 2007-2009 could meet old NMHC+NOx standard of 2.5 g/bhp-hr
  - Or 100% of engines could per certified at half way between 2004 and 2010 NOx standards
    - 1.2 -1.3 gram/bhp-hr NOx
    - EGR used to meet this standard

2007 On-highway Implementation

- 50 Heavy-duty Diesel engine families certified
  - 30 engine families at 1.1 - 1.3 NOx or NMHC+NOx
  - 6 engine families at 1.4 - 1.8 NOx or NMHC+NOx
  - 14 engine families at 1.9 - 2.5 NOx or NMHC+NOx
    - Credit users or phase-out engines
- Cummins Diesel pickup truck certified with NOx adsorber
- Most engines at 0.01 PM
  - 3 engine families at 0.10 PM
    - 3 for 2 engines from early introduction DPFs

On-highway PM Reduction



On-highway NOx reduction

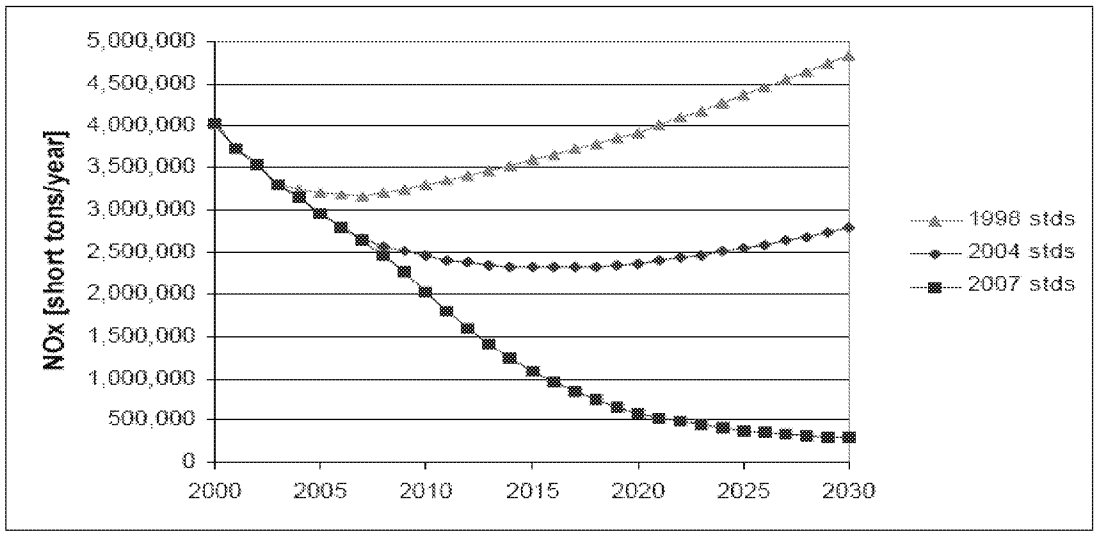


Figure II.B-2. Projected HDDE NOx Emissions Due to 2004 and 2007 Standards

2007-2010 On-highway Costs and Benefits

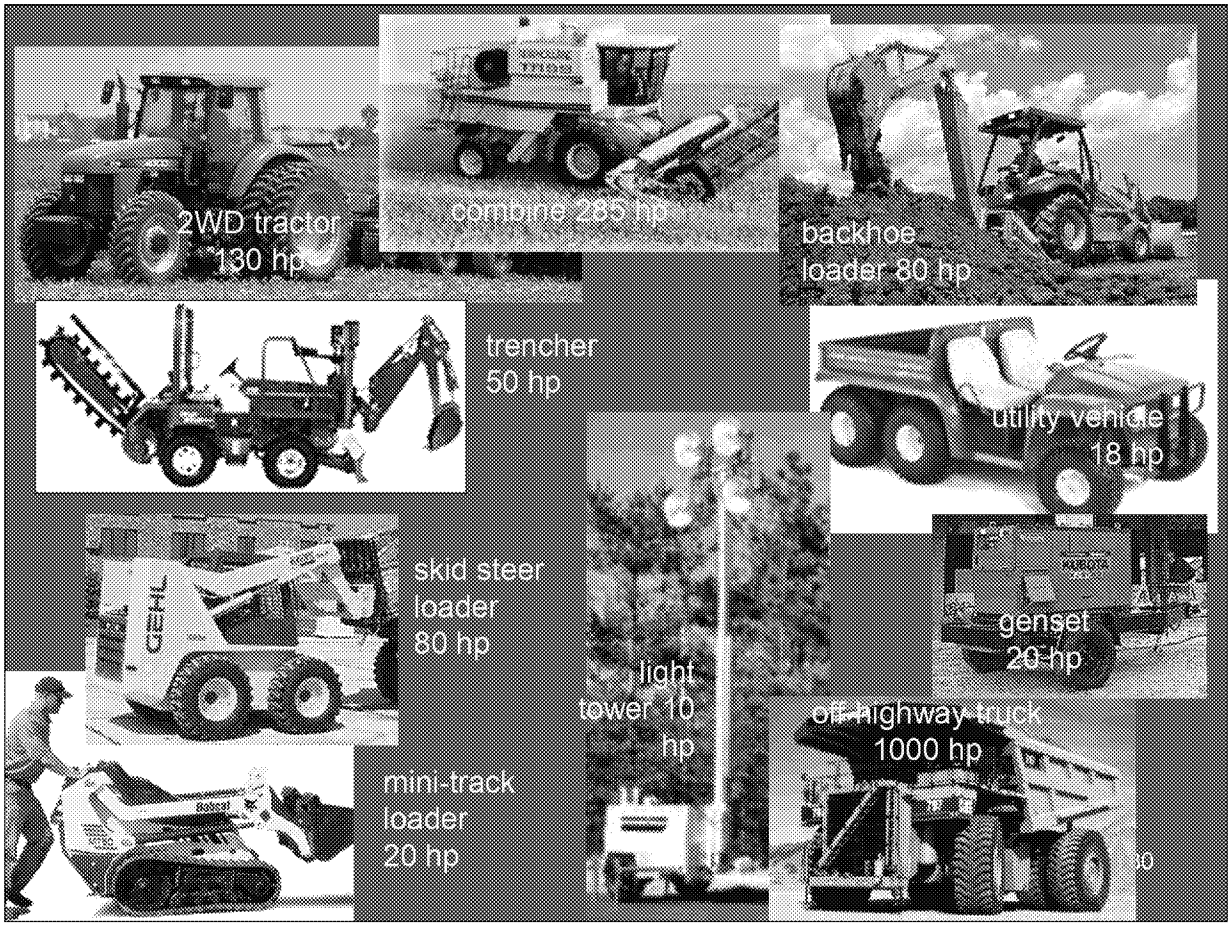
The program will prevent annually:

- Over 8,300 premature deaths
- Over 750,000 respiratory illnesses 1.5 million lost work days
- 2.6 million tons of NOx, 110,000 tons of PM, and 17,000 tons of toxic pollutants

Nonroad Tier 4 Program

Nonroad Diesel Emission Standards

- Nonroad diesel engines first regulated in 1996
  - These regulations do not cover locomotive and marine engines
    - Locomotives and Marine have separate regulations
  - Emissions standards were phased in by engine power
  - By 2000, all power categories of engines were regulated
  - Initially, stationary engines were exempt but new engines are now meeting essentially same emission standards
- Reductions in emissions standards were done in tiers
  - Engines from 37-560 kW will all be Tier 3 by 2008
  - Engines from 0-37kW and > 560 kW are currently Tier 2
- Tier 4 Rule set new emission standards for all engines


2WD tractor
130 hp
combine 285 hp
backhoe
loader 80 hp
trencher
50 hp
utility vehicle
18 hp
skid steer
loader
80 hp
genset
20 hp
light
tower 10
hp
off-highway truck
1000 hp
mini-track
loader
20 hp

Tier 4 Program Overview

- A systems approach of reducing nonroad fuel sulfur levels to enable advanced emission control technology
  - 500 ppm maximum sulfur nonroad, locomotive and marine diesel fuel in 2007
  - 15 ppm nonroad fuel in 2010
- Engine standards representing reductions of >95% PM and ~90% NOx
  - Standards phase in starting in 2008, fully phased in by 2014
  - Expect similar technologies that will be used on highway engines
- California has same standards

Tier 4 Program Overview

- Diesel Fuel
  - Lubricity
    - During rulemaking process, issues were raised over loss of lubricity associated with decreased sulfur in fuel.
      - Specific to certain fuel systems which rely on fuel as lubricant
      - Similar concerns were raised in 1993 when on-highway went to 500 PPM sulfur
      - Some nonroad engines likely running on 500 PPM sulfur for some time
      - Additives used to improve lubricity
      - Inspect older engines for fuel leaks
      - Learn from on-highway experience
  - Energy content about 1% lower for ULSD

Engine Standards Program

500 ppm NR fuel

15 ppm NR fuel

hp	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
<25	Tier 1				PM *(reductions w/oxidation catalysts or engine-based control)*							
25-75					PM *(reduction w/oxidation catalysts or engine-based control)*					**PM: 100%** NOx		
75-175	existing Tier 2								**PM:100%** **NOx: 50%**	**50%**	**100%**	
175-750			existing Tier 3					**PM: 100%** **NOx: 50%**	**50%**	**50%**	**100%**	
>750	Tier 1		existing Tier 2					**PM &NOx: 50%**	**50%**	**50%**	**100%**	

Percentages indicate portion of sales required to meet advanced emission control technology standards

2014 Non-Road CI Emission Standards (grams/kilowatt-hr)

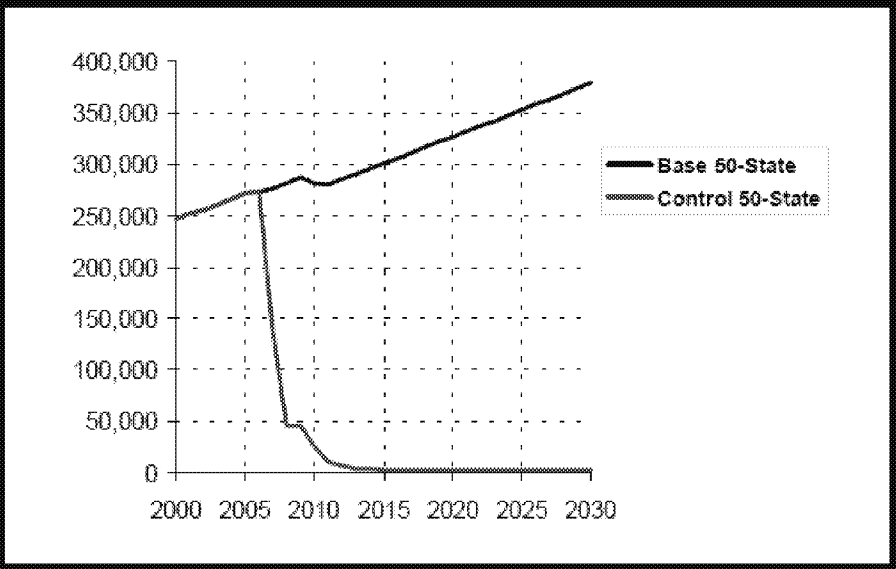
Engine Power	Technology	CO	NMHC	NMHC +NOX	NOx	PM
kW< 19	Diesel Oxidation Catalyst	6.6		7.5		0.40
19 ≤ kW < 56	DPF	5.0		4.7		0.03
56 ≤ kW < 130	NOx aftertreatment and DPF	5.0	0.19		0.40	0.02
130 ≤ kW ≤ 560	NOx aftertreatment and DPF	3.5	0.19		0.40	0.02
kW > 560 Generators	NOx aftertreatment and DPF	3.5	0.19		0.67	0.03
kW > 560 All other	DPF	3.5	0.19		3.5	0.04

Interim Tier 4 Standards (g/kW-hr)

Engine Power	Year	CO	NMHC	NMHC+ NOX	NOx	PM
kW < 8	2008	8.0		7.5		0.40
8 ≤ kW < 19	2008	6.6		7.5		0.40
19 ≤ kW < 37	2008	5.5		7.5		0.30
19 ≤ kW < 37	2013	5.5		4.7		0.03
37 ≤ kW < 56	2008	5.0		4.7		0.30
37 ≤ kW < 56	2013	5.0		4.7		0.03
56 ≤ kW < 130 NOx Phase-in	2012-2014	5.0	0.19		0.40	0.02
130 ≤ kW ≤ 560 NOx Phase-in	2012-2014	3.5	0.19		0.40	0.02

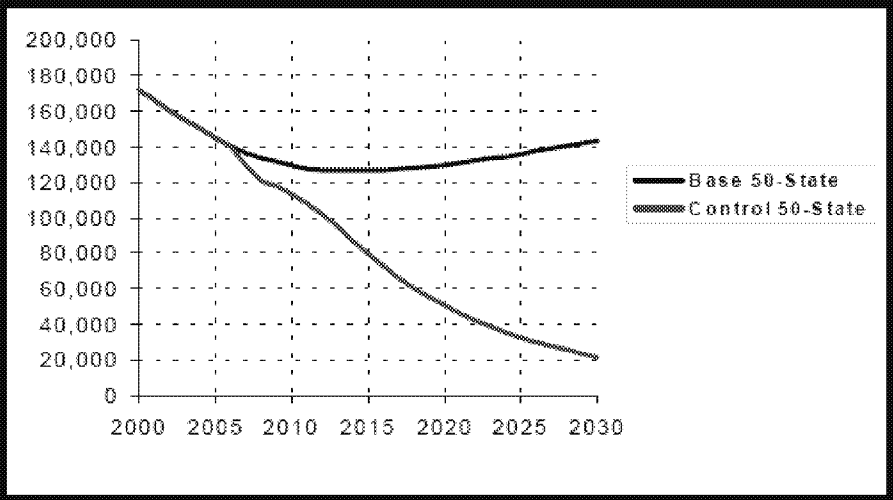
Nonroad SO2 Reduction

Tons SO2



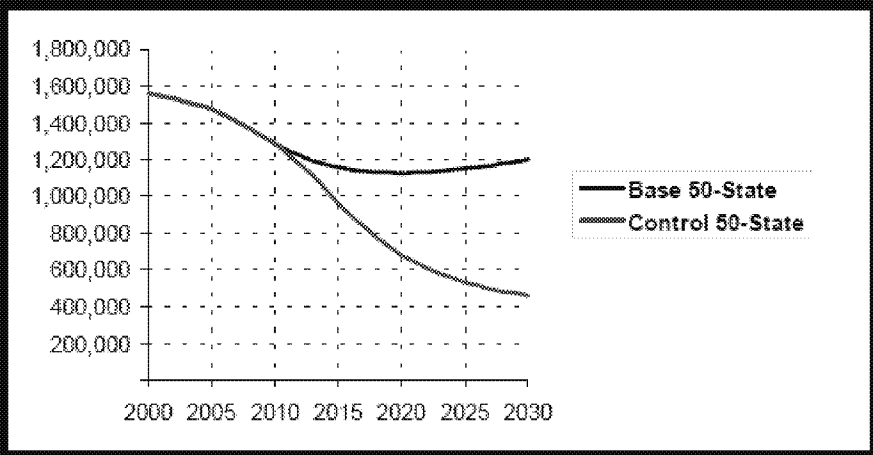
Nonroad PM Reduction

Tons PM 2.5



Nonroad NOx Controll

Tons NOx



Nonroad Benefits

- Program will prevent 9,600 premature deaths; 16,000 nonfatal heart attacks; & nearly 1 million lost work days on an annual basis in 2030
- Total annual benefits exceed $80 billion/year in 2030, annual costs less than $2 billion/year

Equipment Flexibility Program

- Equipment flexibility program, also known as the Transition Program for Equipment Manufacturers (TPEM)
  - Allows equipment manufacturers to use previous Tier engines in some of their equipment
    - For example an Tier 1 (1996 design) 200 Hp engine in 2003 under Tier 2 standards
  - Allows equipment manufacturers to phase-in redesign of equipment to accommodate latest emission control technology
    - EGR equipped engines may require larger radiator which results in an equipment redesign
  - Existing inventory of engines
    - A manufacturer may use up existing inventory of older engines in new equipment but can not stockpile older engines to avoid new standards
  - Engine manufacturer can produce previous Tier engines once notified by equipment manufacturer
    - Equipment manufacturer must be involved in design process
      - For Tiers 1-3 equipment importer is considered a manufacturer
      - Tier 4 prevents importers from being in program

Equipment Flexibility Program

- Tier 4 Programs
  - Percent of production
    - Allows 80 percent of engines summed over 7 years to use previous tier engines
      - For example, 20% of production for 4 years can be previous Tier
      - Exemption is specific for each power category
        - » Tier 3 has 9 power categories
        - » Tier 4 has 5 power categories
      - Generally requires most equipment in a power category to have compliant engines
  - Small Volume Allowance
    - Allows up to 200 engines per year in one engine family to be previous tier, not to exceed 700 over 7 years
      - For multiple engine families
        - » <130 kW, 525 over 7 years not to exceed 150 in a year
        - » >130kW, 350 over 7 years no to exceed 100 in a year

Equipment Flexibility Program

- Hardship Relief
  - Not for manufacturers who manufacturer both engines and equipment
  - Additional hardship relief may be requested
    - For engines greater than 19 kW
  - Small volume equipment manufacturer hardship for engines 19-37 kW

For More Information...

- 2007 Highway Diesel Rule:
  - http://www.epa.gov/otaq/diesel.htm
- Nonroad Diesel Rule
  - Copy of proposal and supporting documents are available from: http://www.epa.gov/nonroad-diesel/
- Equipment Flexibility
  - Yanira Reyes-Morales (reyes-morales.nydia@epa.gov)
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